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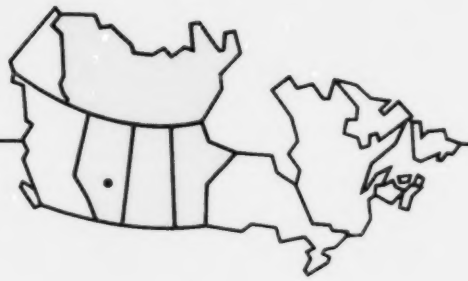
Control studies with carbofuran on seed and cone insects of white spruce

H.F. Cerezke and R.E. Holmes



Information Report NOR-X-280
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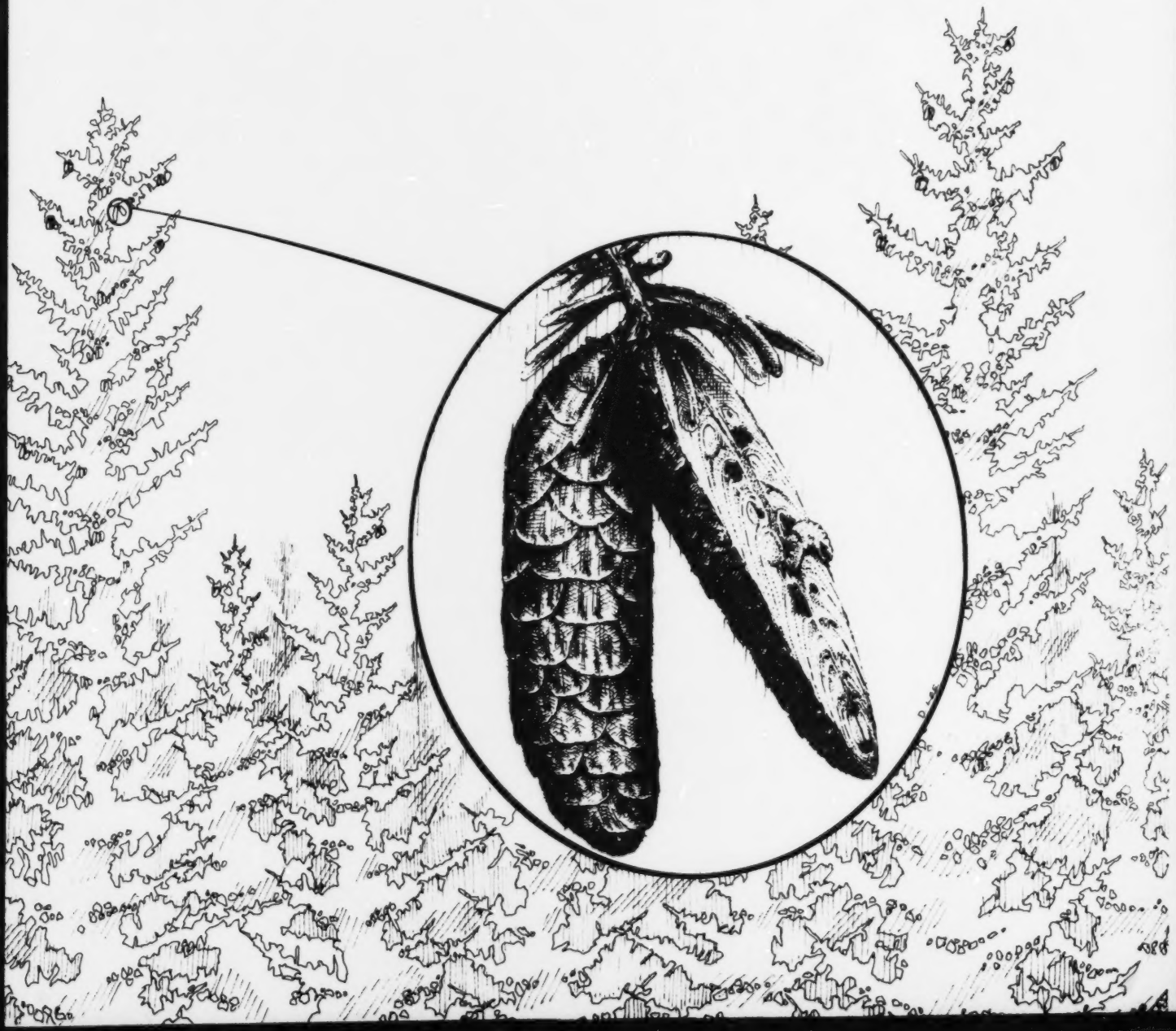

87-01181/

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CONTROL STUDIES WITH CARBOFURAN ON SEED AND CONE INSECTS OF WHITE SPRUCE

H. F. Cerezke and R. E. Holmes[1]

INFORMATION REPORT NOR-X-280

NORTHERN FORESTRY CENTRE
CANADIAN FORESTRY SERVICE
1986

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©Minister of Supply and Services Canada 1986
Catalogue No. Fo46-12/280E
ISBN 0-662-14883-5
ISSN 0704-7673

This publication is available at no charge from:

Northern Forestry Centre
Canadian Forestry Service
5320 - 122 Street
Edmonton, Alberta
T6H 3S5

H.F. Cerezke; Holmes, R.E. 1986. *Control studies with carbofuran on seed and cone insects of white spruce*. Can. For. Serv., North For. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-280.

ABSTRACT

Field plots in stands of mature white spruce (*Picea glauca* (Moench) Voss) near Grande Prairie, Alberta, were treated for control of seed and cone insects by soil application with carbofuran 5G at rates of 4.5, 6.7, and 8.9 g cm^{-1} of tree diameter during late May to early June 1979. Cone and seed samples were subsequently analyzed for insect species and abundance, insect control, seed losses, and phytotoxicity. Eight species of insects were associated with the cones and seeds and caused overall seed losses of 5–6% and 1–2% at two sites. Cones attacked by the most abundant species, *Hylemya anthracina* Czerny, had 46% reduction of potentially viable seeds. Percentage control was most consistent with this species and was proportional to applied rates of carbofuran; reductions in attacked cones varied from 0 to 14% and from 39 to 81% at two sites. Phytotoxic effects attributed to the 8.9-g rate resulted in reduced cone length, numbers of potentially viable seeds, and seed germinability and may have negated any positive gains in seed yield due to the carbofuran treatment.

RESUME

Dans des peuplements d'épinettes blanches à maturité (*Picea glauca* (Moench) Voss) près de Grande Prairie, en Alberta, le sol de placettes expérimentales a été traité au carbofuranne 5G, de la fin de mai au début de juin 1979, à raison de 4,5, 6,7, and 8,9 g pour chaque centimètre du diamètre des arbres, afin de réprimer les insectes qui s'attaquent aux graines et aux cônes. Des échantillons de cônes et de graines ont ensuite été analysés en vue de déterminer les espèces d'insectes et leur abondance, le pourcentage de répression, les pertes de graines et les effets phytotoxiques. Huit espèces d'insectes ont été relevées en rapport avec les dommages causés aux cônes et aux graines, et des pertes de graines de 5 à 6% et de 1 à 2% ont été observées dans deux stations. Dans le cas des cônes attaqués par l'espèce la plus abondante, *Hylemya anthracina* Czerny, la quantité de graines pouvant être viable a diminué de 46%. Pour cette espèce, le pourcentage de répression a été le plus constant, et l'efficacité du traitement a été proportionnelle au taux d'application de carbofuranne; dans deux stations, le pourcentage de réduction dans les cônes attaqués a varié entre 0 et 14% et entre 39 et 81%. Les effets phytotoxiques reliés au taux d'application de 8,9 g/cm se sont manifestés par la diminution de la longueur des cônes, du nombre de graines pouvant être viables et de la faculté germinative; il se peut qu'ils aient contre-balancé l'accroissement de la production de graines dû au traitement au carborfuranne.

CONTENTS

	Page
INTRODUCTION	1
MATERIALS AND METHODS	1
RESULTS	2
Insect-caused Seed Losses	2
Phytotoxicity	4
DISCUSSION	7
REFERENCES	9

FIGURES

1. Relationship between numbers of potentially viable white spruce seeds per bisected surface of each unattacked cone and cone length 5

2. Germination of white spruce seeds from control and carbofuran-treated plots at Sites 1 and 2 near Grande Prairie 6

TABLES

1. Insect species observed in white spruce cones collected at two sites near Grande Prairie in 1979 3

2. Percentage incidence of the five most common species of insects attacking white spruce cones at two sites near Grande Prairie, Alberta, in 1979 3

3. Incidence and infection of spruce cone rust, *Chrysomyxa pirolata*, in white spruce cones collected adjacent to Sites 1 and 2 in mid-July 1979 near Grande Prairie, Alberta 4

4. Estimated percentage seed losses in white spruce cones caused by *Hylemya anthracina* and *Cydia youngana* in late August 1979 near Grande Prairie, Alberta 4

5. Average cone length and numbers of potentially viable seeds of white spruce collected at two sites near Grande Prairie, Alberta, in 1979 7

NOTE

The exclusion of certain manufactured products does not necessarily imply disapproval nor does the mention of other products necessarily imply endorsement by the Canadian Forestry Service.

INTRODUCTION

Increasing quantities of high-quality white spruce (*Picea glauca* (Moench) Voss) seed are becoming necessary in Alberta to satisfy seed requirements for natural and artificial regeneration programs carried out by the provincial government and industry (Hellum 1977). Most seed requirements are currently met from collections made in natural stands during tree felling, from squirrel caches, and from seed production areas established throughout the province (Hellum 1977; Altmann et al. 1980). To ensure adequate seed supplies, cone collecting must be intensified during years of moderate to heavy cone crops. Such crops on white spruce are relatively infrequent, however, and may occur on the average only every 2 to 6 years in the Mixedwood Forest Section of Saskatchewan and Manitoba (Waldron 1965), and less frequently farther north (Zasada and Viereck 1970; Zasada et al. 1978), with light or no crops in the intervening years. In British Columbia the frequency of good cone crops is once every 7 or more years, (Albricht and Birzins 1982), and in Montana on the east side of the Rocky Mountains, Englemann spruce (*Picea engelmannii* Parry) produced two good and four fair cone crops during a 21-year period (Roe et al. 1970).

Insects inhabiting cones and seeds of white spruce may cause damage to over 90% of the cone crop in some years and destroy over 60% of the seeds (Tripp and Hedlin 1956; Bean and Prielipp 1961; Werner 1964; Hedlin 1973, 1974; Fogal et al. 1977). Recognition of this potential loss was the basis of field control tests undertaken in 1979 by Procter and Gamble Cellulose Ltd. of Grande Prairie, Alberta, to establish the feasibility of protecting seeds against insect-caused losses. The Canadian Forestry Service cooperated in the study through posttreatment examinations of cones and seeds and analyses of control data. This report describes the insect species involved, their impact on the seed crop, the results of treatments, and evidence of cone and seed phytotoxicity.

MATERIALS AND METHODS

Two sites were selected for insecticide treatment in the Procter and Gamble Forest Management Area: Site 1 north of Grande Prairie in the Saddle Hills and Site 2 south of Grande Prairie (District 1, Compartment 3 of Procter and Gamble Cellulose Ltd.). Each site was selected for uniformity of stand type consisting of fully stocked white spruce trees 20–25 m tall. At each site 12 plots measuring 15 × 15 m were laid out in a random block pattern. Three served as control plots and had no insecticidal treatment. Three different concentrations of insecticide were applied in the other nine plots, each replicated in three plots.

The systemic insecticide used was granular carbofuran[1] (Furadan 5G: 5% active ingredient), applied at the rates of 4.5, 6.7, and 8.9 g cm^{-1} (0.4, 0.6, and 0.8 oz. per inch) diameter of tree stem, measured at breast height level (dbh). The quantity of carbofuran applied was first calculated on the basis of total diameters of all live white spruce in each 15 × 15 m plot. The granular material was dispensed from plastic bags into shallow furrows scraped to mineral soil, and the duff material was then replaced to cover the insecticide. In each plot the furrows were made at 3–4 m intervals across the plot and similarly at right angles, creating a grid network of furrows closely approximating the average crown projection area of individual trees. At Site 1 the insecticide was applied on May 22–25, 1979, when terminal buds were starting to swell. At Site 2 the application was made during the first week of June when the young female cones had flushed and were in the upright position. The phenological development of the two sites appeared to be similar.

Heavy cone crops were reported at both sites. Samples of cones were collected in mid-July when immature and in late August when mature. The first sample collection was obtained from branches shot down from the upper crown of 10 trees outside of the treated plots at each site. A subsample of 200 cones was randomly selected from each sample and examined for insect species and damage.

Cones for the late-August sample were collected after felling the trees. At each site cones from each replicate of three plots that had received the same rate of insecticide treatment were mixed, and a sample of about 500 cones was collected, yielding a total of about 2000 cones from each site. For the posttreatment examinations, a subsample of 300 cones was randomly drawn from each lot of 500 cones. This provided a total of 2400 individual cone examinations from the two sites. The

[1] Consisting of 2, 3-dihydro-2, 2-dimethyl-7-benzofuranyl methylcarbamate.

cones were stored at 5°C until examinations were completed.

The length of each cone was measured with vernier calipers to the nearest 0.1 mm, then bisected along its mid-length with a sharp utility blade. The insect species and their associated damage on the cut surfaces were identified according to published keys (Hedlin 1973, 1974; Hedlin et al. 1980). Incidence of attack in each cone sample was expressed as a percentage of the total sample. All apparently filled seeds (i.e., undamaged and potentially viable) on each of the two exposed cut surfaces were counted and an average from the two surfaces was used for final analyses.

During examination of the cones collected in the mid-July sample, the cone rust *Chrysomyxa pirolata* Winter, was observed in the spermogonial and aecial stages on the cone scales. Each rust-infected cone was rated on the exposed cut surfaces into five infection classes representing the proportion of scales with aecial spore development: 0–20%; 21–40%; 41–60%; 61–80%; 81–100%.

Control of the five most common insect species was estimated by comparing their incidence of attack in treated plots with that in the control plot at each site. Cones attacked by the two most damaging species, the spruce cone maggot (*Hylemya anthracina* Czerny) and the spruce seed moth (*Cydia (=Laspeyresia) youngana* Kearfott), were selected to estimate the amount of seed they destroyed. Each cone damaged by one mature larva of each species was paired with a randomly selected cone of the same length showing no evidence of insect damage on the cut surfaces. For each insect species comparisons were made by paired t-test for differences between mean numbers of filled seeds in insect-attacked and non-attacked cones.

Cone length and numbers of filled seeds in samples from each treatment plot were compared with those in the control plots by analysis of variance to assess differences likely due to phytotoxicity.

A germinability test, based on procedures of the International Seed Testing Association (Anonymous 1976), was run on samples of 400 apparently sound seeds obtained from opened cones remaining from each of the late-August collections. The seeds were germinated on filter paper in petri dishes, in four replicates of 100 seeds per dish, and stored at a constant 29°C in a moisture-saturated environment. Percentage germination after 21 days was calculated as the average of four replicates for each treatment and control plot at the two sites. Germination was considered successful when the radicle attained a minimum length of 5 mm.

RESULTS

Eight insect species were found associated with the white spruce cones and seeds (Table 1). The incidence of the five most common species of insects is summarized in Table 2 for both the mid-July and the late-August collections. Their abundance was higher at Site 1 than at Site 2, especially *H. anthracina*. Incidence of each species was similar in both the mid-July and the late-August control plot collections, indicating that the earlier collection was representative of the insect species complex and their general abundance.

Estimates of percentage control due to carbofuran treatment are shown in brackets in Table 2 and suggest that the overall control treatment combined for all insects and treatments was more successful at Site 2 (54.6%) than at Site 1 (18.4%). The later date of application at Site 2 may have accounted for its greater success. Control of *H. anthracina*, the most abundant species, was consistent with the increasing rate of carbofuran application at both sites, and similarly for the gall midge at Site 2. There are inconsistencies in the results, however, that can be attributed to the low incidence in insect numbers and to variation within and between plots.

Incidence of cone rust was about four times greater at Site 1 than at Site 2 (Table 3). Length of rusted cones was similar to that of noninfected cones, and most (over 70%) were infected throughout their length. At the time of examination in late July, scales of most infected cones were showing evidence of drying out. Only a few rust-infected cones were observed in the late-August sample.

Insect-caused Seed Losses

The numbers of sound seeds per cone attacked by one *H. anthracina* larva were reduced by an average of 40% (range 36–46%) in cones from treatment and control plots of Site 1 (Table 4). Mean numbers of seeds in attacked cones were all significantly less ($P < 0.01$) than those in unattacked cones. Cones attacked by this insect at Site 2 were not analyzed, but their damage impact can be expected to be similar. Cones attacked by *C. youngana* had 7.9% fewer seeds than nonattacked cones; however, the means were not statistically significant (Table 4). At Site 1 the insects caused an estimated seed loss of 5–6% of the total cone crop, and at Site 2 they caused an estimated 1–2% cone loss.

Table 1. Insect species observed in white spruce cones collected at two sites near Grande Prairie in 1979

Spruce cone maggot, *Hylemya anthracina* Czerny: most abundant insect species present and accounted for most of the seed losses; most larvae were mature at the time of the mid-July collection and many had exited the cone.

Spruce seed moth, *Cydia* (=Laspeyresia) *youngana* Kearfott: present in low numbers; its larvae accounted for some seed loss.

Spruce seed midge, *Mayetiola carpophaga* (Tripp): up to three larvae were exposed on a single cut surface of a cone.

Spruce cone axis midge, *Dasineura rachiphaga* Tripp: larvae of this species appeared to be the second-most abundant but caused insignificant seed loss; some cones had up to five larvae in the central axis.

Spruce cone gall midge, *Dasineura canadensis* Felt: occurred in fairly low numbers, but some cones had up to three larvae exposed on a cut surface.

A spruce cone worm, *Dioryctria* sp., possibly *abietivorella* (Grote): only a few larvae were encountered and all were late-summer feeders; each larva appeared to enter the cone from the terminal end and chewed indiscriminantly on seeds and scales.

A resin midge, *Resseliella* sp.: up to three larvae were exposed on some cones.

A thrips species (unidentified): several cones from the mid-July sample only had 1–2 thrips in the tips of the cone between the scales, but no apparent feeding damage was observed.

Table 2. Percentage incidence of the five most common species of insects attacking white spruce cones at two sites near Grande Prairie, Alberta in 1979[a]

Site and insect species	Mid-July sample (untreated)	Control	Late-August sample Carbofuran treatment (g cm^{-1} dbh) 4.5	6.7	8.9
Site 1					
Spruce cone maggot	12.0	11.3	15.0 (0)[b]	11.0 (3)	9.7^{ns}(14)
Spruce seed worm	0.5	2.7	1.3 (52)	1.0 (62)	1.0^{ns}(63)
Spruce seed midge	3.0	3.7	3.7 (0)	1.7 (54)	2.7**(27)
Cone axis midge	2.0	3.7	4.7 (0)	4.3 (0)	3.7^{ns}(0)
Cone gall midge	1.0	0.0	3.7 (0)	1.3 (0)	1.7^{ns}(0)
Site 2					
Spruce cone maggot	1.5	3.7	2.3 (39)	1.7 (54)	0.7*(81)
Spruce cone worm	0.0	0.7	0.0 (100)	0.3 (57)	1.3^{ns}(0)
Spruce seed midge	1.0	0.7	0.3 (57)	1.0 (0)	0.3^{ns}(57)
Cone axis midge	1.0	2.7	0.7 (74)	1.3 (52)	1.0*(63)
Cone gall midge	1.5	3.0	1.7 (43)	1.0 (67)	0.7*(77)

[a] Sample size was 200 cones from each site for the mid-July collection and 300 cones from each plot within each site for the late-August collection.

[b] Value in brackets indicates percentage reduction compared with control plot.

[ns] Not significant (significance measured in chi-square tests made to compare fit of 8.9-g treated and control plot totals of insect numbers to an expected 1:1 ratio).

[*] Significant at $p < 0.05$.

[**] Significant at $p < 0.01$.

Table 3. Incidence and infection of spruce cone rust, *Chrysomyxa pirolata*, in white spruce cones collected adjacent to Sites 1 and 2 in mid-July 1979 near Grande Prairie, Alberta

Site	Number of cones examined	Percentage cones infected	Average length of infected cones (cm)	Number of cones in % infected classes
1	200	23.5	4.51	21–40%: 2 41–60%: 5 61–80%: 7 81–100%: 33
2	200	5.5	4.03	81–100%: 11

In the analysis of seed loss by comparison of paired cones of similar length, it was assumed that the numbers of sound seeds per cone varied with cone length. This assumption appears to be valid as indicated in Figure 1, which shows the relationship of numbers of sound seeds (potentially viable) on the bisected surface of cones undamaged by insects plotted over cone length. The data from the Site 1 control plot are used as an example.

Phytotoxicity

Mean cone lengths and numbers of sound seeds on the cut surfaces of cones are presented in Table 5 for both collections. Average cone lengths in the mid-July sample were somewhat shorter than those from the late-August control plot sample, indicating their development was incomplete at the time of the first collection. On the other hand, mean numbers of potentially viable or sound seeds per cone were higher in the early sample. This suggests that some seeds aborted and did not complete development, even after mid-July.

For late-August data, mean cone length and numbers of sound seeds in the treated plots were significantly less than for the controls (Table 5). Except for the 6.7-g treatment plot at Site 2, there was a decreasing trend in mean values of cone length and numbers of sound seeds with increasing concentration of carbofuran application. The percentage reductions (Table 5) indicate that for the 8.9-g rate of application, cone length was reduced 7.3% and 20.6% at Sites 1 and 2, respectively, while numbers of sound seeds were reduced 14.9% at Site 1 and 26.2% at Site 2. These reductions are attributed to phytotoxic effects of carbofuran.

Tests of seed germinability indicate similar patterns of germination in control and treatment plots at Sites 1 and 2, except that the level of germination was about 15% lower for seeds from all plots at Site 1 (Fig. 2). Germination of seeds from treated plots was an average of 15% less than that from the respective control plots. This apparent reduction in treated plots is consistent with the results in Table 5 and is attributed to carbofuran toxicity.

Table 4. Estimated percentage seed losses in white spruce cones caused by *Hylemya anthracina* and *Cydia youngana* in late August 1979 near Grande Prairie, Alberta

Insect species and site	Number of paired samples	Average number of seeds/cone surface		Percentage seed loss
		Insect-infested	Noninfested	
Hylemya anthracina				
Site 1				
4.5-g plot	34	6.66**	10.93	39.1
6.7-g plot	27	5.02**	7.80	35.7
8.9-g plot	28	4.71**	7.80	39.6
Control plot	32	5.14**	9.53	46.1
Cydia youngana				
Sites 1 and 2 all plots	23	9.76ns	10.59	7.9

** Means differed significantly at $p < 0.01$ level.
ns Means were not significantly different at $p < 0.05$ level.

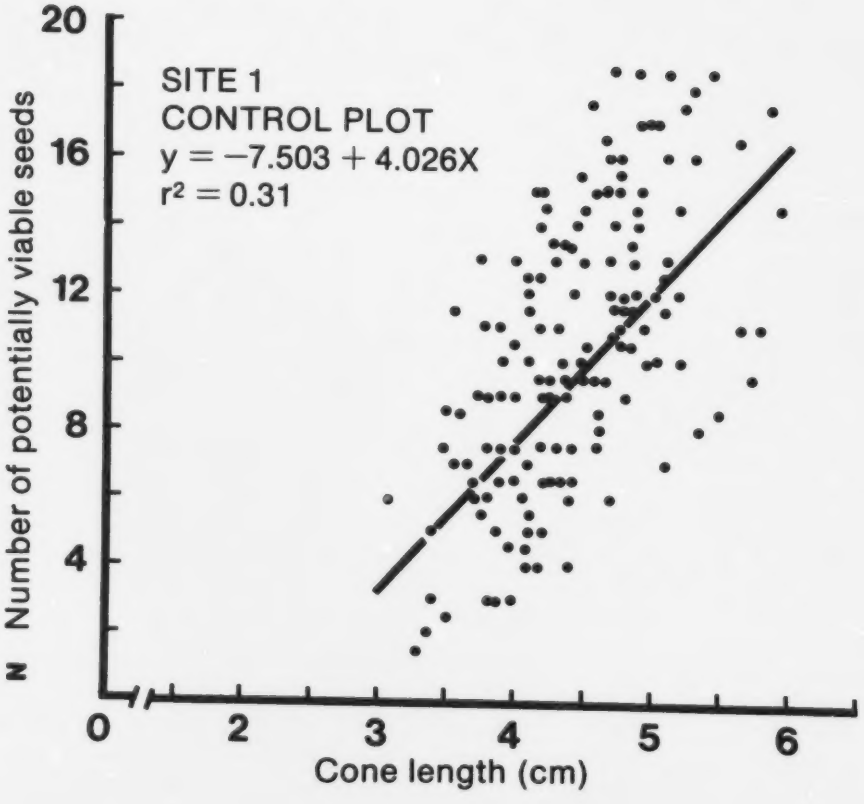

Figure 1. Relationship between numbers of potentially viable white spruce seeds per bisected surface of each unattacked cone and cone length. The data are from the Site 1 control plot near Grande Prairie (n = 235).

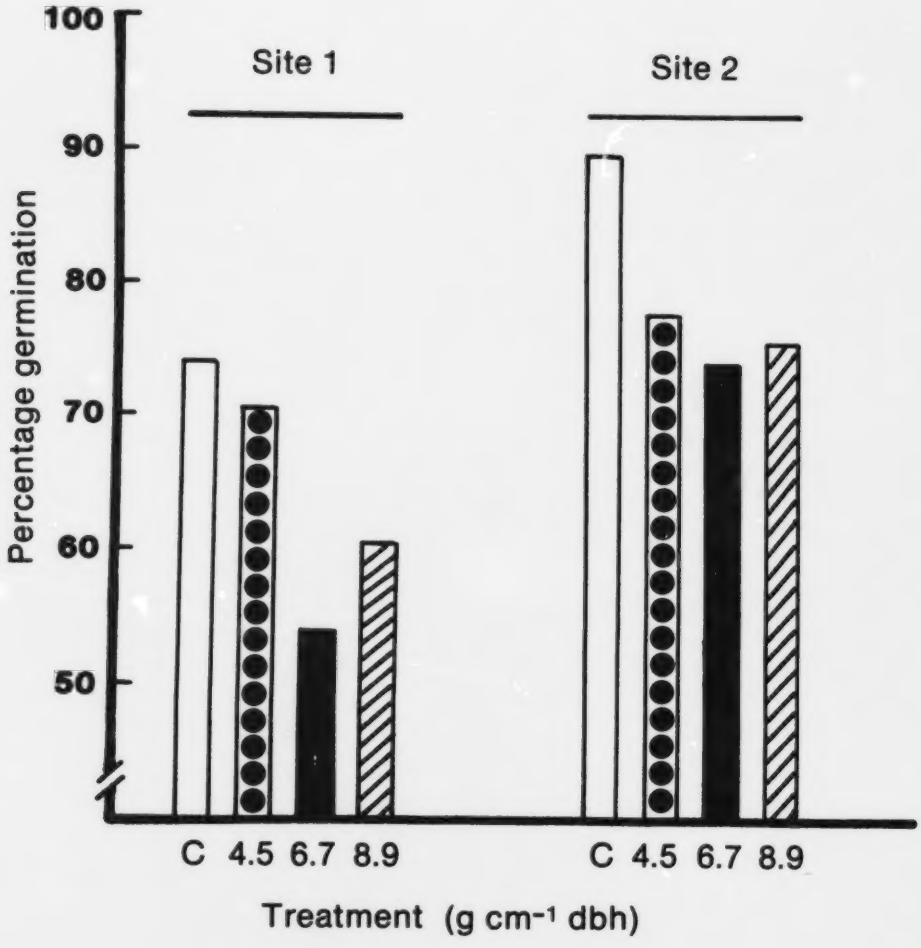

Figure 2. Germination of white spruce seeds from control (C) and carbofuran-treated (4.5, 6.7, and 8.9 g treatments) plots at Sites 1 and 2 near Grande Prairie. Each bar is based on a sample of 400 seeds.

Table 5. Aver. ge cone length (cm) and numbers of potentially viable (sound) seeds of white spruce collected at two sites near Grande Prairie, Alberta, in 1979[a]

Site and measurement	Mid-July sample (untreated)	Late-August sample Control	Carbofuran treatment (g cm^{-1} dbh) 4.5	6.7	8.9	F-test
Site 1						
Average cone length (cm)	4.32	4.38	4.39 (0)[b]	4.32 (1.4)	4.06 (7.3)	**
Average no. sound seeds/cone	13.02	9.52	9.41 (1.2)	8.39 (11.9)	8.10 (14.9)	**
Site 2						
Average cone length (cm)	4.17	4.42	3.68 (16.8)	3.90 (11.8)	3.51 (20.6)	**
Average no. sound seeds/cone	11.51	9.84	7.57 (23.1)	9.94 (0)	7.26 (26.2)	**

[a] Sample size was 200 cones from each site for the mid-July collection and 300 cones from each plot within each site for the late-August collection.
[b] Values in brackets indicate percentage reduction compared with control.
** Differences between treatment plots and control were significant at $p < 0.01$.

DISCUSSION

All species of insects except the thrips found in this study have been previously reported in white spruce cones over a wide geographical area of the northern United States and Canada (Tripp and Hedlin 1956; Keen 1958; Bean and Prielipp 1961; Werner 1964; Hedlin 1973, 1974; Hedlin et al. 1980; Schmid et al. 1981). A seed chalcid, *Megastigmus piceae* Rohwer, reported to be uncommon in British Columbia and Ontario (Tripp and Hedlin 1956; Hedlin 1973) was not observed in this study; however, a *Megastigmus* sp. was reared from white spruce cones from Alberta in 1967 (Tripp and Robins 1968).

Abundances of *H. anthracina* and *C. youngana*, the two most damaging insects to white spruce seeds, are known to fluctuate with cone crop abundance (Tripp and Hedlin 1956; Hedlin 1973), vary at different geographical locations within the same year (Tripp and Robins 1968), and occur in different proportions within different spruce habitats (Fogal et al. 1977). In cones collected from 17 different locations in Alberta in 1967, the incidence of cones damaged by *H. anthracina* varied from 4 to 97% (average 35.8%), and cone damage from *C. youngana* was from 0 to 95% (average 23.8%) (Tripp and Robins 1968). The low incidence of these two species in 1979 may be due to the abundant cone crops produced at Sites 1 and 2, as suggested in other studies (Tripp and Hedlin 1956; Werner 1964).

Of the two species, seed losses have generally been higher from damage caused by *H. anthracina*, though both species tend to cause maximal damage when cone crops are small (Tripp and Hedlin 1956). Maximum seed loss from *C. youngana* may reach 34% when up to 100% of cones are infested, whereas a similar incidence of attack by *H. anthracina* may result in about 60% seed loss.

Because most cones infested by these two species contain one larva per cone, estimates of their seed-destroying potential can be reliably expressed on a per-larva basis. Thus, one *H. anthracina* larva destroyed an average of 55% of the potential seeds per cone in British Columbia, and one *C. youngana* destroyed an average of 40% potential seeds per cone (Hedlin 1973). In this study, populations of *C. youngana* were too low to properly assess seed losses (Tables 2, 4), but for *H. anthracina* the average seed loss per cone was 46.1% in the control plot (Site 1) and 8% less in treated plots (Table 4). The discrepancy of these results with those of Hedlin (1973) are likely accounted for by the different methods used to estimate seed losses and by natural

variability in the numbers of sound seeds produced during different crop years.

Seed losses due to cone rust in the study areas may have exceeded those caused by all insects combined as very few rust-infected cones were collected in the late-August sample. It is believed that many of the rust-infected cones either dropped prematurely, became detached more readily than noninfected cones when trees were felled, or were avoided in the final collection because of their size and appearance. Ziller (1974) reported spruce cone rust to be common throughout western Canada, infecting up to 75% or more of the spruce cones in localized areas during certain years. The overall effects of the rust on cone and seed development may be somewhat variable; however, in studies of rust-affected and healthy white spruce cones in interior British Columbia, Sutherland (1981) reported that the disease significantly reduced seed yield, seed weight, and in some cases, seed germinative capacity. A study by Nelson and Krebill (1982) on *Picea pungens* Engelm. in Utah showed that seed germination was reduced by 25%, cone scales often opened prematurely, and seed release and dispersal were seriously affected by aecial spore masses, cone resinosis, and distortion of cone scales.

Some suppression in insect abundance, particularly of *H. anthracina*, can be attributed to carbofuran application (Table 2); however, the results are somewhat inconclusive. Several factors might account for the poor control results, including the large size of trees treated, time of application, seasonal moisture, and the bioactivity and translocation characteristics of carbofuran in white spruce.

Carbofuran as a systemic, soil-applied insecticide has been widely tested for control of a variety of insect pests on coniferous species (Saunders 1970; Brewer 1972; Pree and Saunders 1972; Kerr and Owebs 1973; Walstad et al. 1973; Merkel and Hertel 1976; Nielsen and Balderston 1977; DeBarr 1978; Fogal et al. 1981; DeBarr et al. 1982; Dix and Van Deusen 1983; Reardon and Barrett 1984). Pree and Saunders (1973, 1974) examined the uptake, translocation, biological activity, and metabolism of carbofuran in *Pinus mugo* and found that concentrations in needles were 100 or more times higher than in buds subsequently produced and that accumulations were proportional to rates applied. Insecticidal residues were detected within 7 days after application and increased in concentration for 60–90 days before declining, but were still detectable for 2 years. The translocation of carbofuran was operative by two or three different metabolic pathways, accumulating mostly in needles and in smaller amounts in roots, trunk, xylem, and buds. In addition, soil pH was shown to affect the persistence of carbofuran since degradation was 7 to 10 times faster in alkaline soils than in acid or neutral soils (Getzin 1973). Thus the persistence and uptake of carbofuran at Sites 1 and 2 should have been adequate to effect some control.

The accumulation of carbofuran residues in the white spruce cones at Sites 1 and 2 was verified by gas chromatograph analysis and showed concentrations varying from 2.8 to 80 mg kg^{-1} in cones collected July 4, July 24, and August 29, 1979[2]. Concentrations were generally highest but most variable in the July 4 collection, were nearly uniform for the July 24 collection, and were proportional to rates of carbofuran applied at both sites only in the August 29 collection. The results from the late-August collection are compatible with those reported by Pree and Saunders (1973) in *Pinus mugo*, and suggest a pattern of slow and uneven uptake of carbofuran in the mature spruce trees that eventually stabilized after July. Inconsistencies in suppressing insects and disease on large trees with systemics have been reported elsewhere and are attributed to uneven movement to all plant parts (Koehler and Campbell 1968; Pree and Saunders 1972; Campana 1979). Although spruce foliage was not analyzed in this study for carbofuran residues, accumulations of this insecticide in the reproductive structures was probably maximal because of the substantially increased mobilization and demand for metabolic reserves that are preferentially translocated for development of the cone crop (Puritch 1972).

The phytotoxic effects attributed to carbofuran in this study (Table 5, Fig. 2) may be surprising because of the large crown size of the spruce trees and consequent dilution of insecticide and the fact that rates of carbofuran used were less than those applied to control insects in several other similar situations (DeBarr 1978; Fogal et al. 1981; DeBarr et al. 1982; Dix and Van Deusen 1983). DeBarr (1979) obtained good control of pine seed bugs and reported no observable phytotoxic effects from carbofuran treatment applied to five species of pine growing in 30 widely scattered seed orchards.

Similarly, good control with carbofuran was obtained for cone and seed insects of eastern white pine (DeBarr et al. 1982), but the highest application rate

[2] Results of consulting report submitted by G.B. Cunningham of Hardy and Associates Ltd., Consulting Engineering and Professional Services, Edmonton, Alberta, in September 1979.

caused slight discoloration at the apex of the current year's needles. Dix and Van Deusen (1983), however, obtained no reduction in damage to seeds and cones of Scotch pine with soil-applied carbofuran, nor were average cone length and average numbers of seeds per cone affected. Similar negative results were obtained on grand fir and Douglas-fir, upon which trunk transplants of carbofuran Medicaps were placed for control of western spruce budworm (Reardon and Barrett 1984). In 17-year-old planted white spruce in Ontario, soil-applied carbofuran provided excellent protection of foliage and reduction in spruce budworm numbers but caused severe phytotoxicity, rated by percentage of needle browning (Fogal et al. 1981). Other investigators using carbofuran applied to foliage and soil have reported visual symptoms of phytotoxicity of *Pinus* species, including needle necrosis and needle tip-burn (Neilsen and Johnson 1972; Pree and Saunders 1972; Walstad et al. 1973; Merkel and Hertel 1976).

In Finland, application of several insecticides to foliage of *Picea abies* during or within a week of the flowering period caused an increase in the number of empty seeds, whereas only minor deterioration of seed quality occurred when treatments were made 3 weeks after flowering (Annila 1973). It was suggested that some insecticides may have a detrimental effect on pollen germination. In control studies of white spruce cone insects in British Columbia, Hedlin (1973) found no harmful effects on seed germination of four foliage-applied insecticides.

The wide variability in results in this and other studies of controlling seed, cone, and foliage insects on coniferous hosts with carbofuran can be attributed to several factors. Dix and Van Deusen (1983) suggested several aspects requiring further research: the levels of soil moisture required to dissolve the carbofuran granules for root absorption; which organs or tissues the carbofuran is translocated to; and whether its concentration within seeds can be associated with treatment levels. There is some evidence that its accumulation within tissues of the cone petiole and seeds or cone scales may differ (DeBarr et al. 1982). Hence, because of their different feeding habits some insects may be more readily controlled than others. Residue analysis of foliage from grand fir indicated very little (less than 1 mg kg^{-1}) translocation occurred within the xylem (Reardon and Barrett 1984). Also, some physiological changes may take place within the tree since an increased production of cone buds occurred on white spruce following carbofuran treatment (Fogal et al. 1981). These authors attributed the increased buds to either the budworm protection or to stimulatory effects related to phytotoxic stress.

Other likely factors contributing to variable control results include different tree species responses, different site conditions, size and age of trees, different rates of applied carbofuran, different methods of application, and possibly root phytotoxicity (DeBarr and Marx 1984). In the present study any positive effects of the carbofuran treatment at Sites 1 and 2 in suppressing seed and cone insects may have been negated by apparent reductions in cone length, numbers of viable seeds, and seed germinability.

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